Model-Based Flaw Localization from Perturbations in the Dynamic Response of Complex Mechanical Structures

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The response of a mechanical structure to vibration is determined by the geometry and mechanical properties of the components that make up the structure. Structural damage in a component can cause observable changes in the overall dynamic response. As a result, vibration measurements are often used in machine health monitoring and for detecting damage in bridges and buildings. In this project, we evaluate the performance of a new model-based approach to locate structural damage in complex mechanical assemblies using measurements of the vibrational response. This model-based method uses a numerical model of the assembly to process the measurements and estimate damage locations. The approach was previously demonstrated on simple objects.

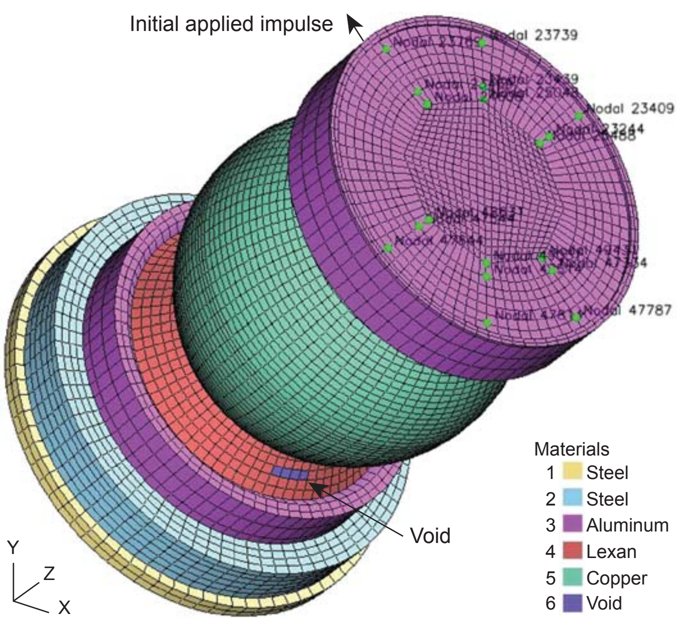

Figure 1. Interior subassembly used for initial test. Green dots are the 18 sample points used for analyzing the vibrational response.

Project Goals

The single goal of this project was to demonstrate the feasibility of the model-based method for localizing structural damage on a complex mechanical structure.

Relevance to LLNL Mission

Present methods for inspection of weapon systems are based on disassembly. Though successful, this method is expensive, time-consuming, and requires removing weapon units from service and transporting them to a central disassembly point.

With DOE's ongoing emphasis on finding more cost-effective ways to maintain the nation's stockpile, alternative methods of inspecting weapons without disassembly will likely play a significant role in future approaches to stockpile inspection. Currently, industry uses vibration monitoring to determine the health of production machinery. Other groups are investigating vibration monitoring for detecting damage in buildings and bridges. LLNL development of this technology will enable the design of internal and external sensor systems for measuring critical structural parameters for surveillance and long-term monitoring.

FY2008 Accomplishments and Results

To determine the relevance of the model-based approach to localizing damage in a complex mechanical structure,

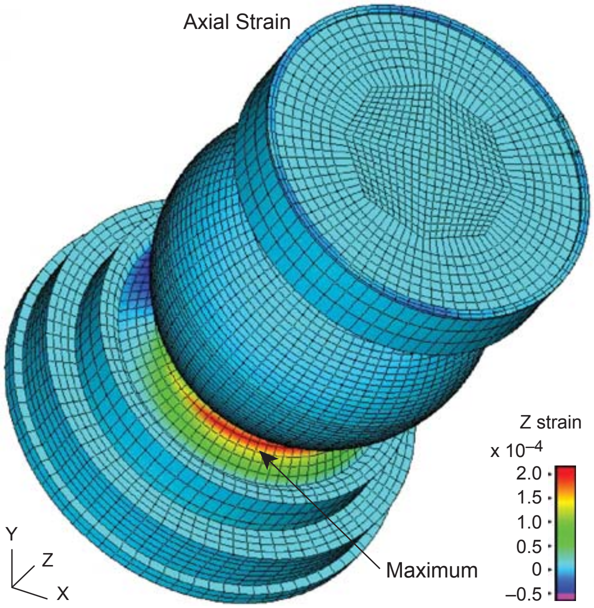

Figure 2. Axial strain field computed from the differences in the vibrational response at the sample points, showing a maximum at the position of the void.

we used the LLNL developed code NIKE3D to calculate the vibrational response of a numerical test structure to a force applied at one point. We first calculated the response to the intact structure, then created a small void in the structure and recalculated the vibrational response. The differences between the vibration patterns at a set of sample points are converted to applied forces in a third simulation of the vibrational response. The location of the damage is estimated from the location of the maximum vibration in this last calculation.

We applied this technique to a numerical model used previously for vibration analysis, changing the materials for several components in order to increase the complexity. The first test was on the interior subassembly (Fig. 1). An impulsive force was applied at one end and the vibration calculated on 18 sample points on one surface. We then created a small void by removing a few elements from a component near the lower surface, and repeated the vibration calculation. The differences between the original and the void cases at the sample points were converted to forces applied at the sample points in the last simulation. The resulting strain field showed a peak at the position of the void (Fig. 2). Next we repeated the procedure for the full model. The resulting strain field again showed a maximum at the position of the void, validating the method for a complex structure.

Project Summary

We demonstrated that the model-based method for localizing structural damage by analyzing vibration data worked for a complex object. This allows one to localize interior structural damage using measurements made on the exterior of a complex structure and a numerical model of the original structure. This is one of a number of possible approaches to damage detection that could significantly reduce the need for disassembly for stockpile inspection. We expect the relevant programs will support further development of this approach.